

## **Marine Mammal Acoustic Tracking from Adapting HARP Technologies**

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### **LONG-TERM GOALS**

The long-term goal of this project is to track swimming and diving marine mammals using their sounds recorded by fixed autonomous acoustic recorders. These localizations will provide estimated acoustic detection ranges which are needed for population abundance estimations using distance sampling techniques (e.g. Buckland et al., 2001).

### **OBJECTIVES**

For omni-directional sounds, such as those made by baleen whales and whistling toothed-whales, large aperture arrays (sensors separated by a few km's) have been successfully used to track calling animals (e.g. McDonald et al., 1995; Tiemann et al., 2004; Frasier et al., 2009). However, large aperture array geometries will not work for narrow-beam signals because not all sensors will receive the same signal. The technical objective of this effort is to record broad-band, narrow-beam acoustic signals (i.e., clicks) with multiple hydrophone sensors in a small aperture array, to provide 3-dimensional bearing angles to echolocating odontocetes.

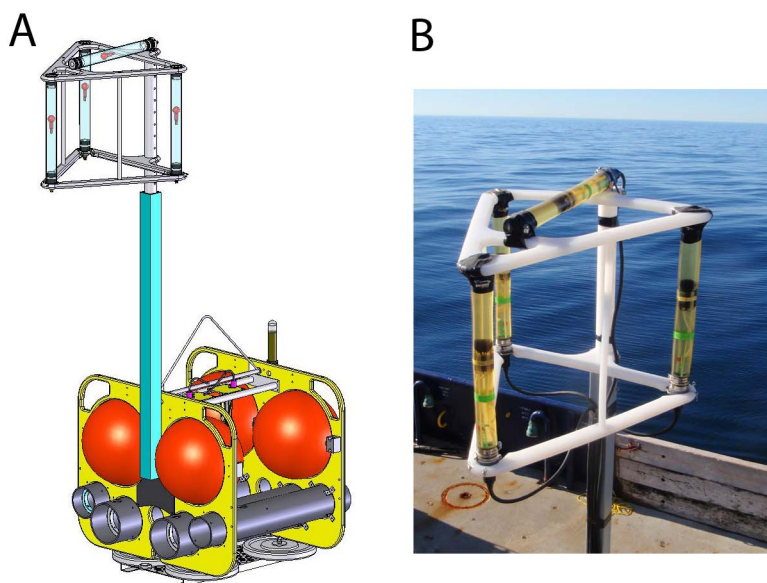
### **APPROACH**

Time synchronization of small aperture array sensor data is critical to calculating accurate bearing angles. Our technical approach is to modify a single channel High-frequency Acoustic Recording Package (HARP – Wiggins and Hildebrand, 2007) to include a four-channel, high-speed Analog-to-Digital Converter (ADC) to provide synchronization of the multi-channel data from a single clock. Multiple data acquisition systems each with a separate clock are more difficult to synchronize, resulting in higher bearing angle uncertainties as well as higher cost.

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Our approach for the small aperture array is to use four broad-band hydrophones arranged in a tetrahedron (Fig. 1) with sensor separations of many wavelengths in the odontocete echolocation frequency range (10's of kHz). The array is rigidly attached about 3m above the HARP seafloor-mounted frame. Besides providing a fixed-array geometry, deploying the instrument on the seafloor provides good geometry for animals echolocating downward, such as foraging beaked whales.

When a toothed-whale emits a click in the direction of the array, it typically will arrive at different times at the four sensors. The Time Difference of Arrivals (TDOAs) between the six fixed sensor pairs (i.e., 1-2, 1-3, 1-4, 2-3, 2-4, 3-4) can be used to calculate a 3-dimensional bearing angle to the sound source. Collecting successive bearing angles from multiple recorders will provide tracking of the sound source.



**Fig. 1. A) Schematic of High-frequency Acoustic Recording Package (HARP) with four channel hydrophone array arranged in a tetrahedron configuration about 3m above the seafloor. B) Photo of tetrahedron array with sensors about 0.5m apart.**

## WORK COMPLETED

### *HARP Modifications*

We developed a four-channel ADC card to work with existing HARP electronics. HARP firmware was modified to record the four digitized signals at a rate of 100 kSamples/sec per channel on to a set of hard disk drives. Standard HARP hydrophones, modified to provide an effective band-width of approximately 2 kHz – 50 kHz, were mounted into a tetrahedron array, and the array was mounted to a HARP frame (Fig. 1). Sensor spacing was about 0.4m – 0.6m or approximately 300 – 400 usec TDOA for a signal along the axis of a sensor pair.

### *Field Work*

On 19 May, 2009 we deployed one four-channel HARP on the west side of San Nicolas Basin offshore of southern California in a known beaked whale foraging area on to the seafloor at about 1000m deep. The instrument recorded continuously, four channels at 100 kHz until the disks drives were full after about one month. The instrument was acoustically navigated to within a few meters using the R/V

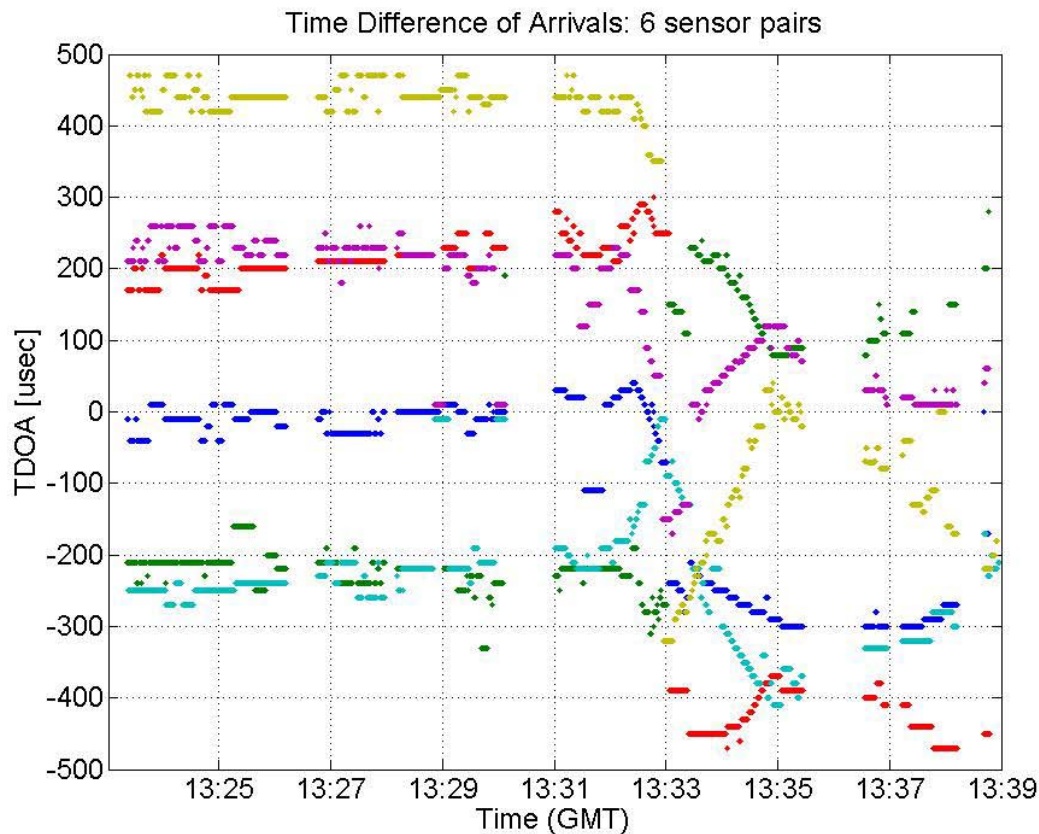
Sproul configured with GPS and acoustic ranging equipment. The navigation procedure also provided acoustic data that was used to orientate the direction and tilt of the hydrophone array. The HARP was recovered on 22 July, 2009.

### ***Data Processing***

The Triton software package developed to allow processing, analysis and evaluation of HARP data (Wiggins and Hildebrand, 2007) was modified to work with multi-channel data including computing Long-Term Spectral Averages (LTSAs) to find events of interest in long duration acoustic data sets. After finding events of interest (i.e., bouts of echolocation sounds), cross-correlating signals between sensor pairs or picking signal first arrivals from the time series waveforms provides TDOAs which allows estimation of 3-dimensional bearings.

## **RESULTS**

From May to June 2009, the four-channel HARP recorded broad-band acoustic data continuously for about one month. Beaked whale echolocation pulses along with dolphin clicks and whistles and ship sounds were recorded. As an example, 16 minutes of TDOAs from the six pairs of sensors were calculated each second from a bout of beaked whale upsweeps (Fig. 2). For the first eight minutes of the echolocation bout, the animals were at a consistent angle from the HARP as shown by the constant TDOAs. Then at 13:31 the TDOA variability increases showing some change in direction and at 13:33 a large change occurs followed by additional direction changes. The sections without any TDOAs are when no pulses were recorded, presumably when the animals were not echolocating or when their echolocation beam was directed away from the HARP. The variability in TDOAs from one sensor pair, especially during the early part of the echolocation bout, may be caused by multiple animals and needs further investigation. The next step will be to transform these TDOAs into 3-dimensional bearings using either a least-squares inverse or match field approach.



***Fig. 2. Time Difference of Arrivals (TDOAs) for the six hydrophone sensor pairs (each sensor pair is a unique color) from 13:23 to 13:39 on 31 May, 2009. The TDOAs are consistent for approximately eight minutes then change quickly at 13:33 suggesting a change in swimming direction.***

## IMPACT/APPLICATIONS

Although data from a single four channel HARP provides valuable information on diving behavior, using an array of these instruments would provide 3-dimensional tracking by cross-fixing the successive bearing from the multiple instruments. In addition to using these recordings to obtain 3-dimensional angles to deep diving whales, the clicks and whistles of passing dolphins can be tracked. These localizations will allow us to estimate detection range for these various species using seafloor acoustic recorders which in turn can be used to provide population abundance estimations.

## RELATED PROJECTS

Project title: Southern California Marine Mammal Studies; Sponsor: CNO N45 and the Naval Postgraduate School; Support from this project allowed for the development of HARP instrumentation and collection of the acoustic data processed for beaked whales with ONR support during N000140910489.

Project title: SBIR Topic N07-024 Marine Mammal Acoustics; awarded to Sonalysts; Sponsor: NavAir PMA264; Support from this project has allowed development of two prototype small aperture array instruments and analysis of data recorded by these instruments in a known beaked whale habitat.

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